Draft CEC PIER-EA Discussion Paper

Agricultural Impacts and Adaptation Options

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Draft CEC PIER-EA Discussion Paper Outline

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Disclaimer

The purpose of this paper is to inform discussions among CEC staff, other state agency staff, non-governmental representatives, representatives of academia and other stakeholders regarding the state of the research on agricultural impacts on and adaptation options for California. In particular, this discussion paper will identify gaps in our understanding and recommendations for future research initiatives with the end goal of supporting informed and systematic planning for climate change. Note that this paper is not intended as a research proposal and should not include recommendations regarding specific research projects.

1.0 Description of Research Topic

California's agricultural sector may be particularly vulnerable to climate change due to its unique set of commodities, reliance on irrigation, and sensitivity to environmental stress—especially for fresh-market horticultural crops. Agriculture represents only 6% of California's total greenhouse gas (GHG) emissions (CEC, 2006) but is expected to be able to play a role in GHG mitigation, and in the cap-and-trade policy that is now being developed. Evaluating risks and designing adaptation strategies for different climate scenarios will be important in maintaining California's stature in U.S. agriculture. California has the largest and most diverse agriculture in the United States, with over 300 commodities contributing to over $30 billion in annual earnings, and half of the nation's fruit and vegetable production (UCAIC, 2006). This report considers research priorities for agricultural mitigation and adaptation to climate change, including the ecophysiology of crop and livestock responses, issues related to the reduction of GHG emissions, risks associated with lower water availability and water quality, and possible changes in regional land use and food systems that may affect energy use, GHG emissions, and agricultural diversification. The agricultural area of research was not included as a separate section in the 2003 PIER research plan, and this report is an opportunity to shape new directions that integrate science and policy for agricultural sustainability.

2.0 Summary of PIER Program Research to Date on Agricultural Impacts and Adaptation Options

Agriculture and climate change have been the focus of several completed PIER research projects. These projects have looked at GHG mitigation strategies in the agricultural sector; agriculture water supply and its impacts on production and economics; vulnerabilities of crops; modeling of crop productivity and GHG emissions; and feedbacks between irrigated agriculture, albedo, and climate patterns. Now underway are projects on agricultural practices to reduce GHG emissions and sequester carbon, and on management of water at several different scales to increase reliability of deliveries and efficiency of agricultural water use. Probabilistic climate projections and downscaling of General Circulation Models (GCM) are contributing to all of these agricultural projects by improving the spatial and temporal resolution of different climate change scenarios.

Several PIER projects have concluded that agricultural GHG mitigation may be significant via soil carbon sequestration, and reductions of soil methane (CH_4) and nitrous oxide (N_2O) emissions (Complex Systems Research Center et al., 2004). Afforestation of rangelands was also found to have a high potential to store carbon at low cost (Brown et al., 2004), but fire is a risk (Petrova et al., 2006). Although an initial scoping study suggested that conservation tillage may also be very effective, a more recent PIER project indicates that this is less viable, based on ecosystem modeling (De Gryze et al., in press). Modeling has also shown that reduction of N_2O emissions via lower nitrogen fertilizer application is an important option for reducing GHG in irrigated agriculture, but that variation among crops, soils, and management practices is high (Complex Systems Research Center et al., 2004; De Gryze et al., in press). Methane (CH_4) emissions from manure management, enteric fermentation, and wetlands have received less research attention. New PIER research will soon deal with management practices to decrease CH_4 in dairy production and N_2O from fertilizer use.

The availability and reliability of water supply is likely to be the most crucial effect of climate change on California agriculture, based on a statewide PIER study on economic impacts that used historical data on water deliveries and transfers, land value, and cropping patterns (Dale et al., 2005). Modeling of water impacts with California's Statewide Water Supply System model (CALVIN) showed that a warm-dry scenario would impose $400 million per year due to water scarcity and operating costs; while adaptation would minimize these costs from a statewide perspective, local deliveries and responses could be strongly affected (Tanaka et al., 2006; Medellin-Azuara et al., 2008). In addition, PIER-supported modeling with the Water Evaluation and Planning (WEAP) system compared agricultural water management for four future climate scenarios in the Sacramento River Basin (Joyce et al., 2006). Lower reservoir levels occurred in all scenarios, but increased groundwater pumping was able to accommodate the higher water demand, and adaptation effectively reduced water use. PIER research is now scaling up to a broader range of issues with the CALVIN model, examining adaptation potential using the WEAP model, and addressing management of reservoir systems.

The complexity of crop responses to increasing temperatures, CO_2, and ozone has been raised in past PIER research, but not in detail. Cavagnaro et al. (2006) provided an overview of the challenges for California agriculture and considered agricultural land-use change in a literature review on the physiological effects of high temperature and CO_2, pest and disease risks, water availability and air quality on the production of crops and livestock. More specifically, Baldocchi and Wong (2006) modeled walnut responses to elevated CO_2 and temperature, and found that transpiration and water demand will increase. They showed that the winter chill hours for flowering of several orchard species are likely to be a limiting factor for production by the end of the century. Another PIER modeling project showed how pest ranges are likely to change, such as the movement of the pink bollworm on cotton to the currently inhospitable San Joaquin

Valley, due to higher temperatures (Gutierrez et al., 2006). Adaptation studies are now underway to model annual and perennial crop responses, and to examine how cropping patterns and land use may change at the landscape level.

Not only will California agriculture be affected by climate change, but agriculture is influencing climate patterns, particularly due to the large expanses of irrigated land, as uncovered by PIER-supported modeling by Jakobsen (2007). Irrigation plus albedo change appears to be responsible for a slight net cooling in California, as well as higher relative humidity, low solubility gases and cloud optical depth, and lower wind speeds.

3.0 PIER Accomplishments

Clearly, a wide range of topics have been considered in the PIER-funded agricultural research during the past five years. The 2003 PIER Research Plan placed high priority on: (1) how climate change may exacerbate the stresses on California's water delivery system, including agriculture; and (2) how soils sequester carbon and the potential for GHG mitigation. Both topics have been expanded far beyond the guidelines of the 2003 PIER Research Plan, and in fact, agricultural issues have merited more attention than originally recognized.

4.0 Non-PIER Accomplishments in this Area and Opportunities for Collaboration

New concerns for agricultural adaptation to climate change was prompted by a study on climate change projections and impacts on several types of California ecosystems; strong impacts occurred for agricultural ecosystems as represented by wine grapes and dairy production (Hayhoe et al., 2004). For perennial crops, Lobell (2006) found that climate change in California will likely decrease the yields of almonds, walnuts, avocados, and table grapes by 2050, using statistical models developed from 1980–2003 records of statewide yield, monthly average temperatures (minimum and maximum), and rainfall variation. Vicuña et al. (2007) found that anticipated shifts in runoff would lead to long-term changes in surface water supplies to irrigated agriculture, ranging from a decrease of 30% to an increase of 5% by 2100. The recent report of the Climate Change Science Program (CCSP) Synthesis and Assessment Product 4.3 (SAP 4.3) (Backlund et al., 2008) highlighted management of Western reservoir systems as an important nationwide issue for agriculture, and concluded that this is very likely to become more challenging as runoff patterns continue to change. This report also provides a pertinent review of physiological effects of climate change on specific crops and rangelands. In the Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC) cautions that major challenges are projected for crops that are "near the warm end of their suitable range or which depend on highly utilized water resources" (IPCC, 2007). One of the more important shifts in planning for climate change in arid and Mediterranean-type climates is the recognition that agricultural impacts in California may be considerably higher than for rain-fed, grain-producing Mid-West agroecosystems, as they will be less likely to benefit from warmer temperatures and a longer growing season (Cline, 2007).

5.0 Research Underway/Committed to via PIER Process

[To be provided.]

6.0 Gaps in Research/Knowledge Relevant to California

The extent and direction of agricultural productivity and agricultural land-use change in California will depend on the global capacity for mitigation of GHG emissions, and the local and regional strategies that are developed to cope with uncertainties in temperature and precipitation (Cayan et al., 2006). Agriculture in California is complex, diverse, and has shown the capacity for resilience to change in the past (Alston et al., 1994). Historically, California has been able to mobilize natural, financial, human, social, and physical capital to adapt to new challenges (Jackson, 2007). However, while this also would be expected for dealing with mitigation and adaptation to climate change, planning for climate change implies planning for agricultural sustainability—i.e., for support of maximum agricultural productivity and profitability, environmental quality, and social well-being—and this is likely to represent a challenge, given the uncertainty ahead.

Mitigation and adaptation to climate change will most likely occur when they achieve multiple benefits in addition to commodity production—i.e., provide other ecosystem services, such as water and air quality, biodiversity conservation, and cultural and aesthetic value (Daily, 1997). At present, there is no comprehensive monitoring or modeling approach that can cover the complexity of issues involved in agricultural adaptation to climate change. The following review thus considers four of the key topics that are likely to play important roles in this process in the next few years: (1) crop and livestock responses, (2) mitigation of GHG emissions, (3) water use and hydrology, and (4) regional land use and food systems.

Crop and livestock responses to rising temperatures and CO_2 concentrations

In the past, CO_2-fertilization effects on crop growth were thought to be higher than is now apparent based on analysis of recent field-based free-air CO_2 enrichment (FACE) experimental results (Long et al., 2006). This is largely due to differing results that occur in the greenhouse versus FACE experiments. One explanation is that plant acclimation to CO_2, in which growth slows to approximately 10–15% above ambient controls, is more pronounced under field conditions. Also, there is growing recognition that plant growth can be limited by the complex relationships between soil microbial carbon and nitrogen transformations, and plant nitrogen assimilation (de Graaff et al., 2006; Bloom, in press).

In addition to temperature and CO_2, crop responses to deteriorating air quality and ozone need more attention. California increasingly receives pollution transported across the Pacific Ocean from Asia's industrial coal burning operations, and poor air quality reduces the solar radiation intercepted by plants (Chameides et al., 1999; Menon, 2004). Also, aerosols have local effects on volatile organic compounds and ozone that directly reduce crop productivity (Chameides et al., 1999; Mauzerall and Wang, 2001).

Most of California's commodities are specialty crops. Compared to field crops, these horticultural crops are more sensitive to short-term environmental stresses that affect reproductive biology, water content, visual appearance, flavor, and quality, and they are likely to be more impacted by climate change and extreme events (Backlund et al., 2008). For crops such as stone fruits and grapes, water stress, temperature, and the timing of precipitation can be extremely important for yields and maximizing fruit quality. Yet there are few monitoring studies or simulation models for use in climate change assessments for horticultural crops, compared to the major grain and oilseed crops.

Another unique feature of California's agriculture is its winter-wet, summer-dry rangelands for livestock production, which may benefit from warmer temperatures during the winter period of highest productivity, or alternatively, may decrease in productivity or become more vulnerable to drought (Shaw et al., 2002).

Some of the important research needs related to climate change adaptation for crop and livestock production are:

- Improve the understanding of physiological processes that may increase or decrease the productivity of California's diverse crops (e.g., growth responses to elevated CO_2, effects of higher temperatures and water stress, "carbohydrate sink limitation" that may limit the utilization of photosynthate, soil nitrogen limitation due to changes in soil/microbe/root biology, and capacity for nitrate assimilation).
- Gain a better understanding of physiological response of livestock to warmer temperatures and drought, and examine options for adaptation for both irrigated and rangeland agroecosystems, including shifts in plant species composition and forage quality of rangeland, as well as availability and productivity of feed crops.
- Develop networks to monitor and model phenology of crops, quality, diseases and pests, and create a database to use for planning adaptive strategies for different regions of California. Special attention should go to extreme events that could indicate thresholds for production of specific crops.
- Anticipate the risks for high-value, salt-sensitive crops that may occur under climate change scenarios that are drier than present climate.
- Assess the tradeoffs of alternative pest-control methods for methyl bromide, which depletes stratospheric ozone.
- Use the findings from improved ecophysiological research on crops and livestock, to develop and adapt models for California's unique commodities that can predict production and economic consequences for different climate change scenarios.

GHG emissions and carbon storage in California agriculture

As climate change progresses, changes in agricultural management are needed in order to maintain soil quality with less dependence on fossil fuel-based inputs, as the cost of these inputs is rapidly increasing, and they also contribute to GHG emissions. Nitrogen fertilization is one example. Elevated CO_2 is likely to increase the nitrogen demand of crop plants (de Graaff et al., 2006), and excessive nitrogen is a major reason for high emissions of N_2O, a significantly more potent GHG in terms of warming potential compared to CO_2 and CH_4. Improved management options, such as precision agriculture, drip irrigation with fertigation, and increased soil nitrogen cycling (e.g., via legume inputs and turnover) offer some potential solutions, but any implementation of changes in nitrogen delivery and management poses tradeoffs for crop productivity. The management options to mitigate GHG emissions are not completely understood and, therefore, their efficacy to address climate change is uncertain.

The effects of fertilizer nitrogen extend far beyond the edges of crop fields, since it moves to groundwater, surface water, wetlands, and the atmosphere. The agricultural "nitrogen cascade" (Galloway et al., 2003) has yet to be studied in terms of full impacts on GHG emissions at the landscape and regional scales in California (Figure 6-1).

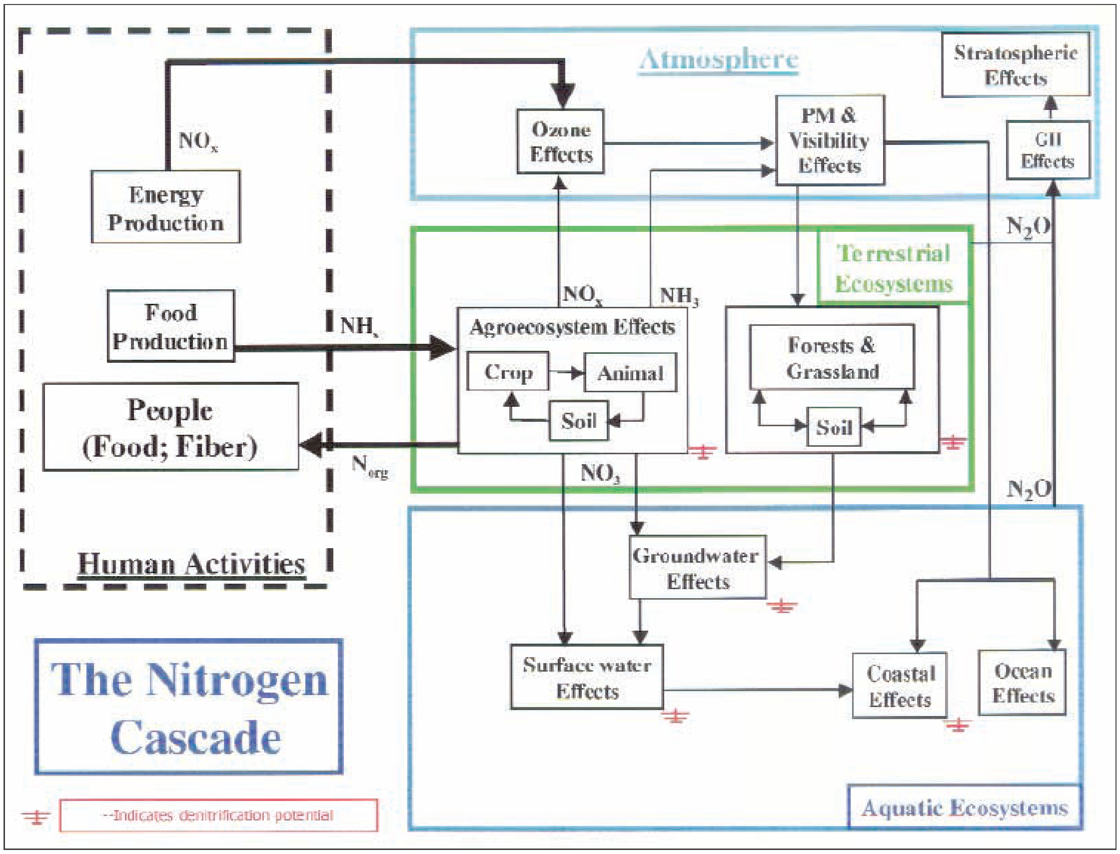

Figure 6-1. Nitrogen cascade showing nitrogen processes as a nitrogen atom is converted from a nonreactive to a reactive form. Abbreviations: GH = greenhouse effect, NH_3 = ammonia, NO_3 = nitrate, NO_x = nitrogen oxide, N_2O = nitrous oxide, PM = particulate matter. (Galloway et al., 2003)

Half of California's agricultural GHG emissions are from N_2O (CEC, 2006), mainly due to microbial nitrification and denitrification of fertilizer and soil nitrogen that is mineralized from soil organic matter, breakdown of crop residues, and manure. CH_4 emissions are also substantial, at 37.5% of agricultural emissions, mainly from enteric fermentation of livestock, manure management, and to a lesser extent, from residue decomposition in anaerobic soils (e.g., rice). The remainder of agricultural GHG emissions is CO_2 (12.5%), released from the decomposition and burning of organic residues, or combustion of fossil fuels are used to power field equipment or processing systems (Figure 6-2).

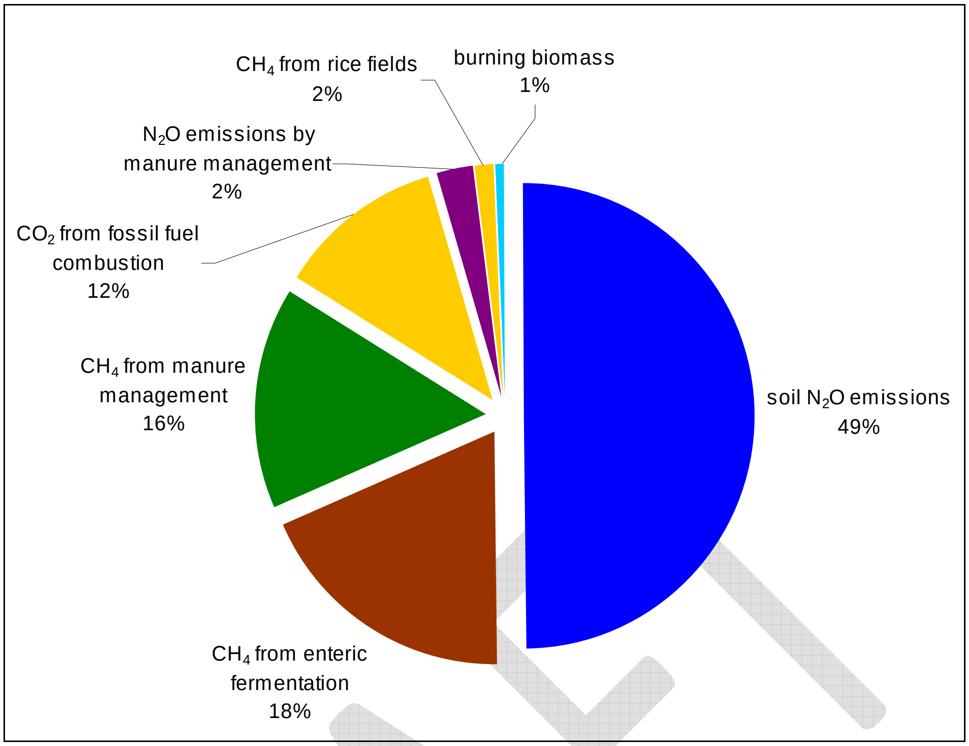

Figure 6-2. Relative sources of anthropogenic GHG emissions in California agriculture. (CEC, 2006)

While information on GHG emissions and carbon storage have recently become available for California agriculture (Burger et al., 2005; Kroodsma and Field, 2006; Kallenbach, 2008; De Gryze et al., in press), there is a shortage of information for farmers to use in decision-making. One issue is that most of the data have been conducted on research stations, rather than on farms that tend to use more tillage, less cover crop biomass, less compost or manure, more nitrogen fertilizer, and different crop commodities. On-farm research is particularly needed for alternative practices, such as cover crops, compost and manure applications, farmscaping (non-production perennial plantings along farm margins, riparian corridors, or tailwater ponds), and for a diverse set of horticultural crops, which can differ markedly in inputs and management.

The following research topics will improve the understanding of agriculture's role in GHG mitigation:

- Develop annual budgets of GHG (especially N_2O) emissions and soil carbon storage under different irrigation and fertilizer practices as used on actual farms, and on a range of soil types, with emphasis on vegetable, orchard and vineyard systems (also including carbon in woody above- and belowground biomass), due to their high inputs and statewide importance.

- Conduct mechanistic research on microbial and abiotic factors influencing soil N_2O emissions via nitrification versus denitrification, and for CH_4 emissions in livestock systems, for use in process modeling, and for improving irrigation, fertilizer, and manure management.

- Compile a database of fertilizer, manure, and fossil fuel inputs for California's many types of commodities and cropping systems, to be used in regional and statewide models, and for farmer education to reduce GHG emissions.
- Use case studies at the watershed level to measure the full impact of the agriculturally-driven "nitrogen cascade", and quantify the relative importance of different processes and ecosystems for N_2O emissions, and for other nitrogen impacts such as water quality.
- Examine the full life cycle analysis for biofuel crops and their tradeoffs in terms of economic profits and other ecosystem services.
- Improve the agricultural accounting mechanisms for use in the statewide cap-and-trade system for reduction in GHG emissions (e.g., through alternative practices for nitrogen inputs, cover crops, organic agriculture, farmscaping, biofuels, etc.).

Regional-scale impacts of global climate change on irrigated agriculture

Potential changes in irrigation water demand and supply will have impacts on cropping patterns, groundwater pumping, groundwater levels, soil salinity, and crop yields. Increasing demands for irrigation water, as well as potential reductions in surface water supply, will put increased pressure on limited groundwater resources. This will lead to risks of groundwater depletion (Alley et al., 2002), land subsidence (Galloway et al., 1999), and resource degradation by soil and groundwater salinization (Schoups et al., 2006). In California, groundwater resources have historically been available to supplement surface water supplies for irrigation. In many other irrigated regions worldwide, groundwater overexploitation and overdrafts have degraded groundwater quality, increased salinity, and depleted groundwater systems (Gleick, 2004). Research is needed to better understand climate change effects on hydrologic processes in California to avoid these problems in the future.

Some of the key issues for agricultural research on hydrology and climate change are:

- Understand regional-scale impacts of changes in water supply under different adaptive management scenarios (e.g., groundwater pumping and land fallowing) using downscaling of GCM climate projections for watersheds at risk—such as the Salinas Valley and the Westside of the San Joaquin Valley—and combine these climate projections with modeling of crop water demand, regional hydrological modeling, and simulations of subsurface flow, salt transport, and land subsidence.
- Determine how crop water demand will be affected by the combined increases in temperature and CO_2 concentration—such as responses of stomatal closure, transpiration, growth patterns, and growing season length—and examine how these responses may change cropping patterns and water demand on a regional scale.
- Examine the effects of water transfers and alternative soil and water management practices on energy use (e.g., pumping costs) and other ecosystem services related to water availability and water quality.
- Develop monitoring systems for changes in air quality and ocean currents, since they may be driving changes in weather patterns that influence the timing and availability of water resources.

- Assess the economic tradeoffs of local versus statewide impacts of climate change on hydrology and water availability under different climate change scenarios, so that planning for adaptation can take place at multiple scales.

Regional land use and food systems

California agriculture is composed of many different landscapes, each with different sets of commodities, resources, and marketing strategies. For this reason, effective planning for mitigation and adaptation to climate change is likely to occur at the regional level, although driven by statewide policies. A "place-based' analysis of climate change is now being conducted for Yolo County, and has engaged several county organizations to develop local awareness for the changes ahead (Jackson et al., in preparation). Ultimately, many of the decisions that will perpetuate California agriculture are local, including responses to climate change.

Urbanization is the single most important factor driving agricultural land-use change in California. California's population is expected to increase to 90 million people by the end of the 21st century. In San Joaquin Valley counties, 35% of the prime agricultural land may be lost in the same time frame, along with much of the remaining agricultural land in coastal counties, even when agricultural risks due to climate change are not considered in the projections (Landis and Reilly, 2003). Farmland loss to urbanization will undoubtedly increase GHG emissions, but models are needed to make these projections.

Urban conversion of agricultural land has occurred at rapid rates in many of the world regions with Mediterranean-type climates; high population growth and urban expansion have often resulted in less self-sufficiency in terms of producing local food, and this is also due to the export values of the many specialty commodities that can be grown (Rosenzweig and Tubiello, 1997). California may run into such a situation if adequate plans are not made for the risks associated with climate change.

Associated with urbanization are changes in food systems, and these may be accelerated by climate change. Diverse, locally-based, more self-reliant food economies may be more resilient to climate extremes, especially for small and mid-scale farms in California, which already have a difficult time competing in highly consolidated commodity markets. Conversely, California may expand its role in world markets if it is able to make projections about climate change elsewhere—e.g., altering commodity choices in response to projected competition.

There are few regional monitoring studies that track land-use change and its associated consequences for agriculture and environmental resources. In fact, regional land-use change is often not known for much of California historically, although a broad synthesis has been made for the entire state (Williams et al., 2005). Not only is there a need to monitor changes associated with urbanization, but also to show how ecosystem restoration in agricultural landscapes may reduce GHG emissions as well as provide other ecosystem services—e.g., wetland restoration, revegetation of marginal lands, and enhancement of wildlife habitat in riparian corridors. Current observation systems are likely inadequate for separating the impacts of climate change on agriculture from other impacts, such as population growth, changes in markets, and resources upon which agriculture depends (e.g., water and air quality).

Some of the important research needs related to land-use change and food systems are:

- Develop models and templates for agricultural counties to help them assess how climate change will affect their agricultural landscapes (e.g., commodities, GHG emissions, water resources, water and air quality, biodiversity, economic value, and potential for land use change).
- Establish monitoring and inventory systems to document changes in commodities and agricultural practices, restored agricultural lands and biodiversity, and effects of urbanization of agricultural land at the regional scale.
- Find ways to increase agricultural energy efficiency at the regional scale (e.g., centralized distribution centers or local processing facilities) considering California's many types of unique agricultural commodities and landscapes.
- Conduct life cycle analysis of agricultural commodities and wastes at the regional level to improve the recycling of end products, use of energy, and reduce GHG emissions.
- Use demographic and urban projections for climate change scenarios, combined with downscaled climate projections, and GIS data on agricultural production, to identify vulnerable commodities and rural communities at different time scales.

7.0 Conclusions and Prioritized Recommendations

7.1 Conclusions

With foresight, planning, and investment, California is likely to maintain the productivity and diversity of its agricultural sector in the face of climate change, although there will be local difficulties. Horticultural crops will require more research than field crops, as they are more vulnerable to environmental stress. Water resources are very likely to be the most crucial factor for adapting to climate change. Agriculture offers some potential for mitigation of statewide GHG emissions, but the greater research emphasis should be placed on adaptation strategies. Adaptation solutions need to be integrated across farm, regional, and statewide scales.

7.2 Prioritized Recommendations

The recommendation of this paper is that the highest priority for upcoming research be placed on developing information and databases that can be used together with GCMs to forecast vulnerabilities of California to climate change. It is apparent that there is not adequate information for planning specific adaptation strategies for most cropping systems and landscapes, given the many ways that agricultural management affects the economics and environmental quality in California. The next phase of research must serve to build public awareness of future vulnerabilities, and to engage the agricultural community not only in thinking about GHG emissions (ETAAC, 2008), but also in adaptation strategies. The active participation of the agricultural community would be expected to have a far greater influence on policy for adaptation than research findings alone.

In terms of specific prioritization, the following topics appear to be most related to PIER objectives, and are likely to generate relevant information for policy within the next few years.

- Assessment of vulnerabilities of horticultural crops and specific growing regions that are likely to suffer from water availability under different climate change scenarios (e.g., thresholds of environmental stress, potential for pest and disease problems, resource limitations, quality of agricultural products, and potential for reduced energy use in farming and processing operations).
- Monitoring networks to track crop phenology and livestock production risks county-by-county, as well as management practices that adapt production to extreme events.
- Full life cycle analysis showing energy use and GHG emissions (e.g., for California's major commodities, biofuel production, and fertilizer and manure).
- Modeling of regional land-use change under different climate change scenarios, including potential changes in food systems, marketing, and the ecosystem services that provide environmental, cultural, and aesthetic benefits to society.

State funding is scarce for most of these high-priority topics. The strong regional emphasis will be likely to elicit more support from state agencies than federal programs, although there may be opportunities for nationwide collaborations, such as through the National Ecological Observatory Network (NEON), the National Phenology Network (NPN), and U.S. Geological Survey (USGS) programs on water resources.

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